Vacuum Tests for the TITAN Cooler Penning Trap (CPET)

by

Scott Foubister

4th Year Physics,

Thompson Rivers University

Kamloops, BC

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Abstract

This report summarizes the vacuum tests for the titanium vacuum tube that will eventually contain the TITAN Cooler Penning Trap (CPET). Scott Foubister, Paul Delheij, and Mel Good performed these tests in the ISAC I Experimental Hall at TRIUMF in May – August 2009. The project goals were to build a vacuum test setup, design and install a baking system, establish a base pressure of less than 1.5×10^{-11} Torr, and determine the effects of some critical materials on the vacuum. Extremely low pressures were required because the tube will contain highly charged ions, which have a much higher tendency to capture electrons from the background gas. The titanium tube was connected via a 4-way stainless steel cross to a turbomolecular pump, which was backed by a roughing pump. After 25 days of pumping, the tube reached a base pressure of less than 1.2×10^{-10} Torr. While the tube was pumping down, a baking system featuring copper heating wires and multiple layers of insulation was designed and installed. The purpose of the baking system was to heat the tube to 180 – 200 °C for several days in order to increase the outgassing rate of materials in the tube walls, allow the pumps to remove the gases, and leave the system with a lower base pressure after cooling for approximately half of a day. After the empty tube was baked and cooled, the pressure dropped below 1.5×10^{-11} Torr (the lower limit of the gauge controllers). After testing the empty tube, different materials being considered for insulating the leads of the penning trap electrodes were placed inside the titanium tube and the effects on the pressures were observed. First, a 5” by 20” sheet of 0.003” thick kapton plastic was tested. This sheet had twice the surface area that would be required to insulate all of the electrode leads. Next, two 6” long cylindrical ceramic insulators with diameters of 0.19” and 0.25” were tested. This represented only 1% of the total length that would be needed to insulate all of the electrode leads. Due to the different geometries and heat capacities of the materials, it was not possible to clearly determine which material had the least effect on the vacuum. However, in both tests the pressures again dropped off-scale after baking and cooling; therefore, we concluded that both ceramic insulators and 0.003” thick kapton are suitable for ultra-high vacuum use.

Background

The Cooler Penning Trap

A penning trap is a device that uses magnetic and electric fields to store ions (1). The cooler penning trap (CPET) will be an important addition to the TITAN setup that will improve the resolution for ultra-precise mass measurement experiments. The CPET is still being designed, but it will eventually be placed inside the titanium vacuum tube that was tested this summer. The vacuum tube will then be placed inside a 7 Tesla superconducting magnet. The penning trap contains three electrodes which, in combination with the magnetic fields, trap ions for up to one second (1). While inside the trap, the ions undergo a complex motion involving three different types of oscillation (1). The actual mass measurement procedure involves several steps (1). First, a radiofrequency (RF) field that couples with the product of two of these oscillation frequencies is applied. Next, the ions are extracted and sent to the Measurement Penning Trap (MPET), where they undergo similar oscillations. Another RF field is applied and once again the ions are extracted. The time of flight from the MPET to a detector is measured, and from this the resonance frequency and hence the mass of the ions can be determined (1). A more detailed overview of the CPET and the TITAN facility can be found elsewhere (2).

Highly Charged Ions

The resolution *R* of such a mass measurement is given by equation [1] below, where *t* is the amount of time the ions are trapped, *q* is the charge of the ions, *B* is the strength of the magnetic field, *N* is the number of time-of-flight measurements for all RF frequencies, and *m* is the mass of the ions (1).

$$R = \frac{tqB\sqrt{N}}{m} \quad [1]$$

The magnetic field is already very high (7 Tesla) and it is limited by the design of the superconducting magnet. The trapping time cannot be increased further because the ions are radioactive and they decay quickly. The number of measurements is already high and the mass of the ions cannot be changed. Therefore, a good way to increase the resolution is to increase the charge of the ions.

However, using highly charged ions (HCI) causes two problems (3). Firstly, HCI have a much higher tendency to capture electrons from the background gas. This means that a much higher level of vacuum is required in order to ensure that enough HCI make it to the penning trap in the same charge state. If too much charge exchange occurs with the background gas in the vacuum tubes on the way to the penning trap, there will be a wide charge state distribution and fewer ions will be in the desired charge state.

Other parts of the TITAN beamline have pressures of approximately 10^{-8} Torr, but the CPET requires much lower pressures because of the higher probability of charge exchange and the longer time the ions are present in the trap (3). Ions pass through other parts of the beamline in tens of microseconds, but in the CPET they are trapped for hundreds of milliseconds (four orders of magnitude longer). Ideally, the vacuum would be four orders of magnitude lower (10^{-12} Torr) in the CPET. However, for our tests we set the goal of reaching less than 1.5×10^{-11} Torr because this value was the lower limit of the ionization gauge controllers we used.

The second problem with using HCI is that the process of charge breeding (which occurs in the Electron Beam Ion Trap) not only increases the charge of the ions but also increases their temperature, which decreases the resolution of the final mass measurement (3). The CPET solves this problem by trapping the HCI for up to a second so they can be cooled via long-range Coloumbic interaction with a cold medium (either electrons or protons). The end result of including the CPET in the TITAN system will be a factor of 10 increase in the resolution of the mass measurements, from approximately 10^{-8} to 10^{-9} (3).

Baking

Baking is a method of raising the temperature of a vacuum chamber to speed up the process of outgassing in order to improve the base pressure (4). Outgassing is the slow release of gases that are absorbed or adsorbed in the walls of a vacuum chamber (5). As the temperature of a solid material increases, so does the vapour pressure and outgassing rate of the gases within (5). The general idea of baking is to release some of the gases from the chamber walls and allow the vacuum pumps to remove them the system. Baking also removes the thin layer of water that adsorbs to chamber walls when they are exposed to air (4). After baking for several days, the heaters are turned off and the temperature of the vacuum chamber returns to normal, as do the vapour pressures of the gases in the walls. The overall outgassing rate is lower because some of the gases were removed by baking; therefore, the base pressure inside the chamber is lower than it was before baking. The duration and temperature of the bakeout depend on the materials used and the temperature sensitivity of the surrounding components in the system.

Objectives for Summer 2009 Vacuum Tests

The first goal for this project was to set up a pumping station to test the titanium vacuum tube that will eventually hold the cooler penning trap. Once the pumping station was set up, the second goal was to determine what level of vacuum could be reached in the empty tube – first without baking, then after baking at 180 – 200 °C for approximately 2 days and cooling for approximately half of a day. The goal was to achieve a base pressure of less than 1.5×10^{-11} Torr, which was the lower limit of the ionization gauge controllers we used.

The final goal was to investigate the outgassing behaviour of different materials by placing them inside the vacuum, baking for approximately 2 days, cooling for approximately half of a day, and then recording the base pressure. We tested kapton plastic and ceramic insulators, both of which are materials being considered for insulating the leads of the penning trap electrodes (which will eventually be placed inside the vacuum tube).

Vacuum Test Setup

At the start of May, the titanium tube arrived at TRIUMF and a test setup had to be built from the ground up. First we set up a pumping station, and then we designed and installed a baking system while the tube was pumping down.

Pumping

Initial Setup

The titanium tube had an outside diameter of 4.5" and an inside diameter of 4.26". It was welded to a 4 5/8" titanium conflat (CF) flange on one end and an 8" titanium CF flange on the other. The total length of the tube and flanges was 51.5".

Before the tube could be connected to the pumping station, it had to be cleaned thoroughly. The purpose was to remove all dirt, oils, and contaminants in order to meet the extreme cleanliness requirements of ultra-high vacuum (UHV). We followed the TRIUMF UHV Cleaning and Assembly Procedures (see Appendix A, also available on the internal section of the TITAN website) for all components added to our vacuum system.

The titanium tube was the most challenging to clean due to its large size. We started by washing all surfaces of the tube in a soapy water solution. We used a drill with an abrasive cloth attached to the end of a long drill bit to clean the inside of the tube. Next, we used a grinder to remove any grease that was present on the welds between the tube and the flanges. After this, we rinsed the tube, washed it again in soapy water, and then rinsed it with deionized water. We decided to skip the ultrasonic cleaning steps of the procedure because of the tube's large size and the fact that it would have to be cleaned again before it was moved to the final setup. However, we followed the full UHV cleaning procedure for all other components added to the system. Once all of the components were cleaned and dried, we set up the pumping station shown in Fig. 1 below.

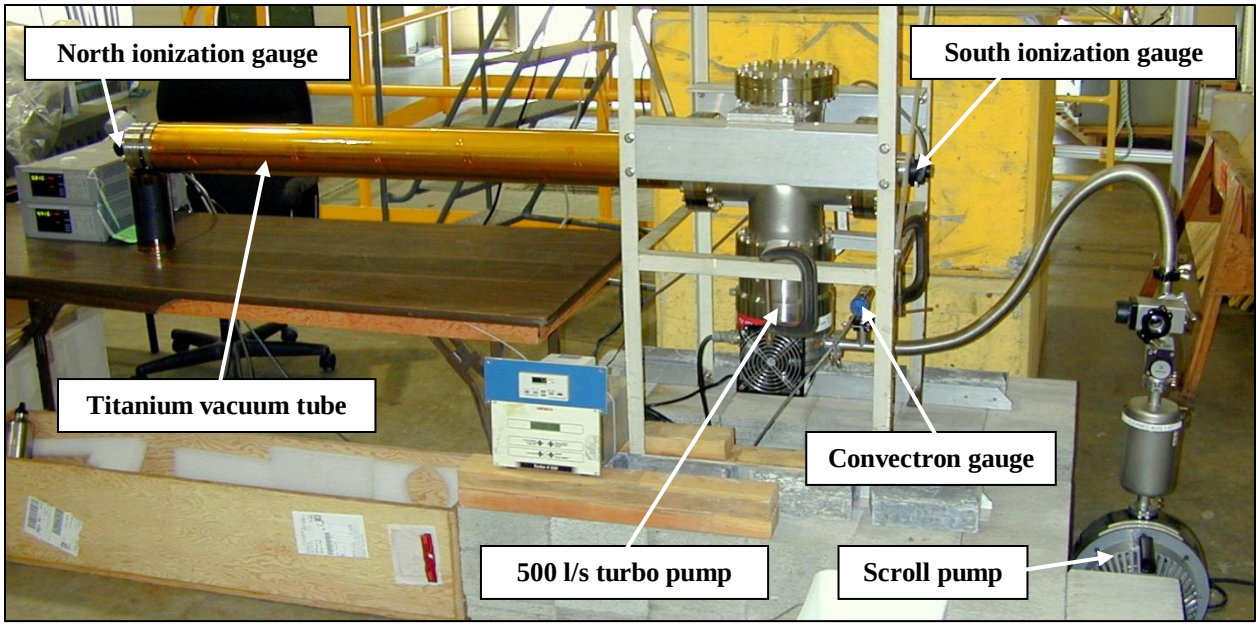


Fig. 1 – Pumping station for testing the titanium vacuum tube that will hold the TITAN Cooler Penning Trap. The tube was connected via a stainless steel cross to a 500 l/s turbomolecular pump, which was backed by a scroll pump. A convectron gauge monitored the pressure between the pumps and two ionization gauges monitored the pressures at the North end of the titanium tube and the South end of the cross.

The 8" flange of the titanium tube was connected to North 8" flange of a 14" wide by 14" tall stainless steel cross. Conflat flanges and copper gaskets were used for all flange connections. A turbomolecular pump (Varian TV 551 Navigator, 500 l/s pumping speed) was connected to the bottom flange of the cross. The turbo pump was connected to a scroll pump (Franklin Electric model 1201006416) via a flexible metal hose, and the pressure in the hose was monitored by a convectron gauge (Granville-Phillips model 275). Two pressure gauges (Varian UHV-24p Nude Ionization Gauges) were installed – one on the South end of the cross and the other on the North end of the titanium tube. These gauges had an operating range of $1 \times 10^{-3} - 5 \times 10^{-11}$ Torr, with reduced performance down to the x-ray limit of 5×10^{-12} Torr. The gauge controllers (Varian Sentorr, UHV configuration) had operating ranges of $1 \times 10^{-1} - 1.5 \times 10^{-11}$ Torr. We chose to use two gauges so we could check the consistency of our measurements. The North gauge was farther away from the pump, so we expected it to have a slightly higher pressure than the South gauge. We used a leak detector (Varian 979 Mass Spectrometer Helium Leak Detector) to check the system for leaks periodically.

August Additions

After several months of testing, the base pressure of our system had risen slightly. In August, we made several additions to the system to attempt to lower the pressure and troubleshoot the problems (see Fig. 2). First, we added a 70 l/s turbo pump (Varian Turbo-V250 MacroTorr) as a backing pump for the main 500 l/s turbo pump. Next, we installed a residual gas analyzer (SRS RGA200) on the top of the cross to look at the trace gases remaining in our system.

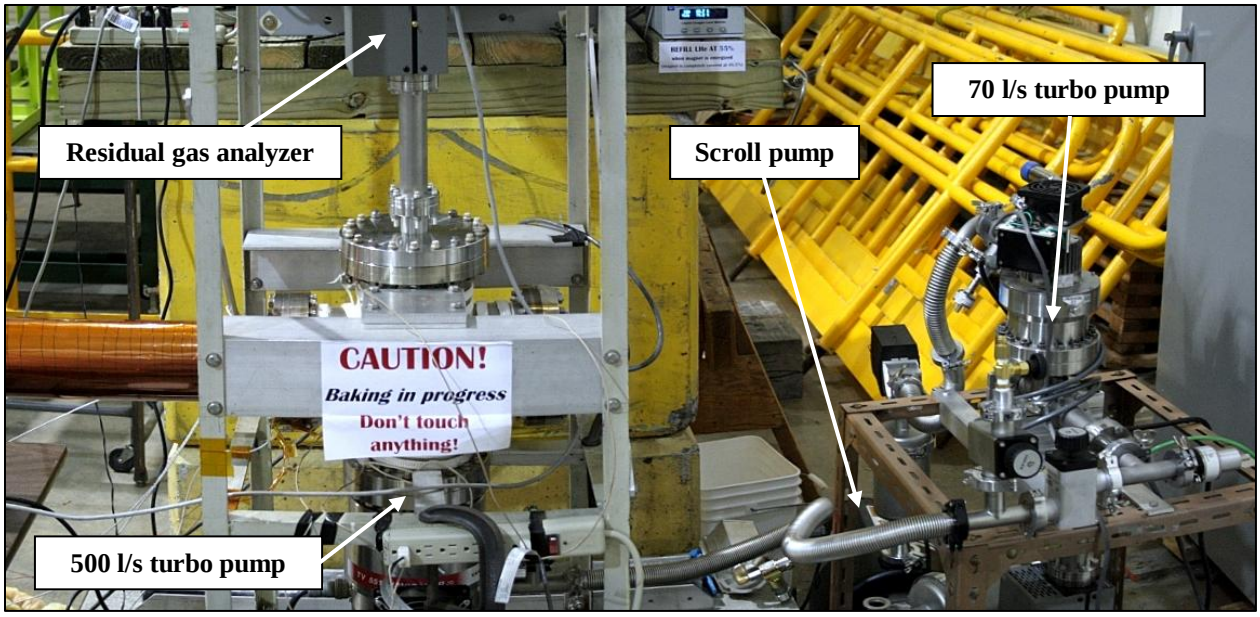


Fig. 2 – August 2009 additions to the vacuum test setup. A residual gas analyzer was added to the top of the stainless steel cross and a 70 l/s turbo pump was installed between the 500 l/s turbo pump and the scroll pump.

After seeing several leaks in the connection between the flanges of the titanium tube and the stainless steel cross, we installed a stainless steel nipple (Fig. 3) to separate the two flanges to allow us to figure out which flange was causing the leak.

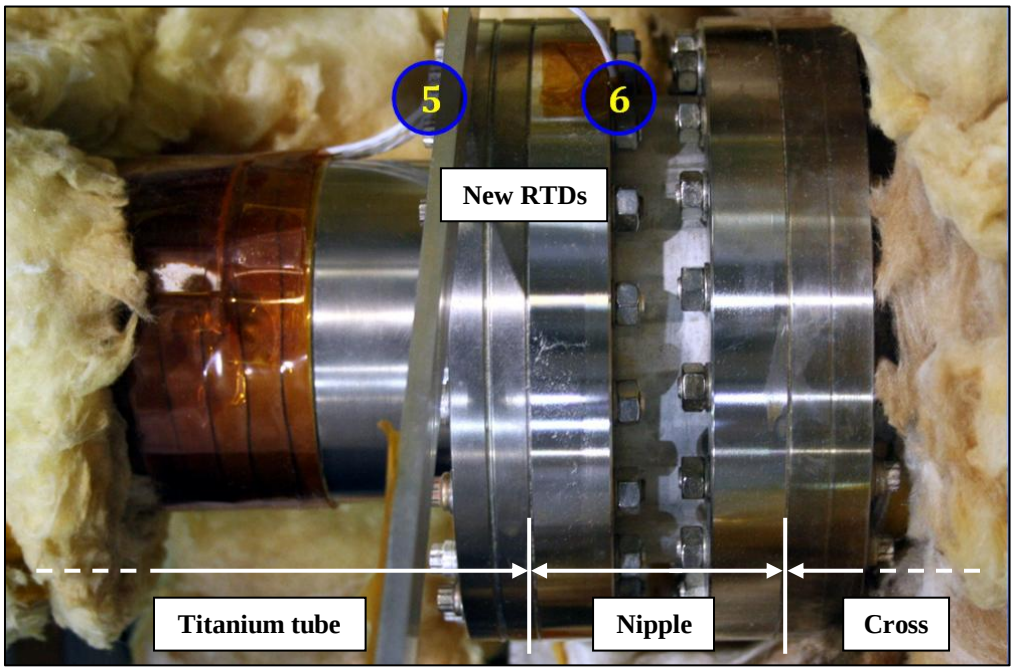


Fig. 3 – A leak was found on several occasions at the connection of the titanium tube and stainless steel cross flanges. A stainless steel nipple was installed to separate the problem flanges and help figure out which one was causing the leaks. Two resistance temperature detectors (labelled 5 and 6) were added to monitor the temperatures on both sides of the titanium tube / nipple connection.

Baking

Overview

The goal was to bake the titanium tube at 180 – 200 °C for approximately 2 days in order to improve the vacuum. We needed to design a baking system with two important constraints in mind. The first constraint was the tight clearance around the tube in the final setup. The 4.5" titanium tube will eventually be placed inside the 5.02" diameter bore of the superconducting magnet, which meant the baking system had to be compact enough to fit within the ¼" clearance around the vacuum tube. The second constraint was that the temperature of the magnet bore was not supposed to go above 40 °C. This meant that the heating system had to reflect heat back to the tube and conduct heat along the tube and out the ends of the magnet bore. We chose a maximum baking temperature of approximately 200 °C to avoid overheating the magnet bore or the insulation materials of the baking system. Note that the vacuum tests this summer were performed outside of the magnet bore, but the system was designed to work inside the magnet bore.

Details

We decided to wrap the tube with copper wires and various other layers of insulation. We used a 30 V power supply (Xantrex HPD 30-10 Regulated DC Power Supply) to send a current through the wires and heat the tube resistively. We prepared the tube by wrapping a sheet of 0.001" thick kapton around it to prevent any shorts from occurring if the insulation on the heating wires failed (something that happened often when testing the wires). Kapton is a versatile polyimide film that remains stable up to 400 °C. Next, we wrapped approximately 29 feet of 0.010" diameter copper wire around the tube. We chose this length and gauge of wire so we could deliver roughly 150 W of power to the tube using only the 30 V power supply. In the end, the 0.010" wire proved to be too fragile – it overheated and broke when its temperature went above 230°C. When this happened, we removed the 0.010" wire and wrapped approximately 78 feet of 0.025" diameter copper wire around the tube. Next, we wrapped the tube in a sheet of 0.003" thick kapton to reduce heat loss from convection. This second baking system (Fig. 4) delivered roughly the same amount of power, but it was more durable and heated the tube more uniformly.

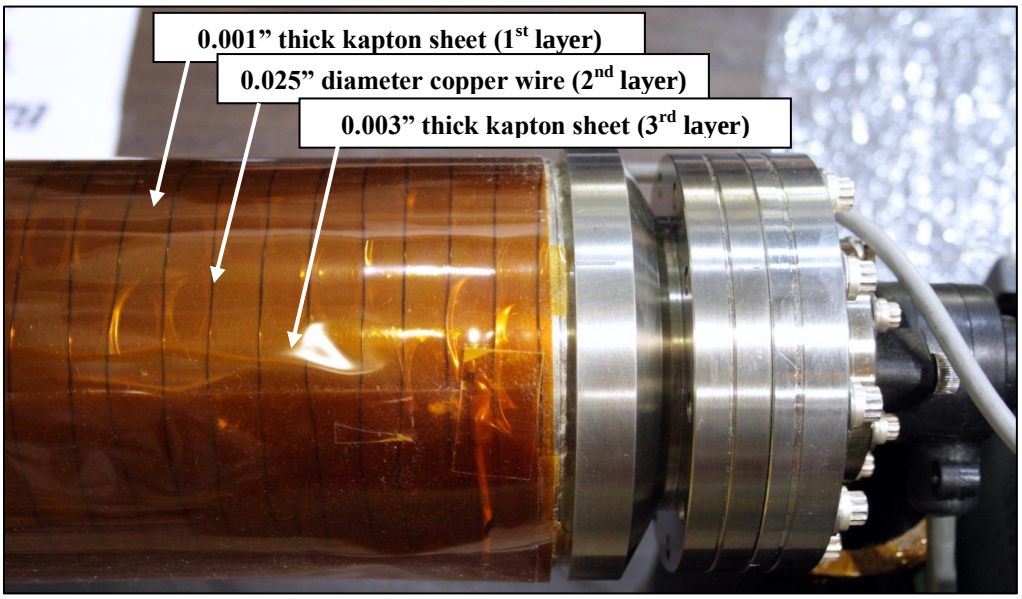


Fig. 4 – Close-up of the first three layers of the new baking system for the titanium tube. A 0.001" thick kapton sheet was wrapped around the tube, followed by approximately 78 feet of 0.025" diameter copper wire, and finally a 0.003" thick kapton sheet.

Finally, we wrapped the whole tube in approximately 2 – 4" of standard household fibreglass insulation (Fig. 5). This allowed us to reach the 200 °C temperature goal, but it was a temporary solution – in order to fit inside the magnet bore, the final baking system will require insulation that is much more compact.

To bake the stainless steel cross, we used two 8-foot long flexible heating ropes (Omegalux model STH 051-080, 657 W each) connected to a variable power supply (Staco Energy model 3PN1210B Variable Autotransformer). We also completely covered the cross with 2 – 4 inches of fibreglass insulation (see Fig. 5). Even though it will not be present in the final setup, the cross was part of the test setup and therefore it needed to be baked to reduce its outgassing rate.

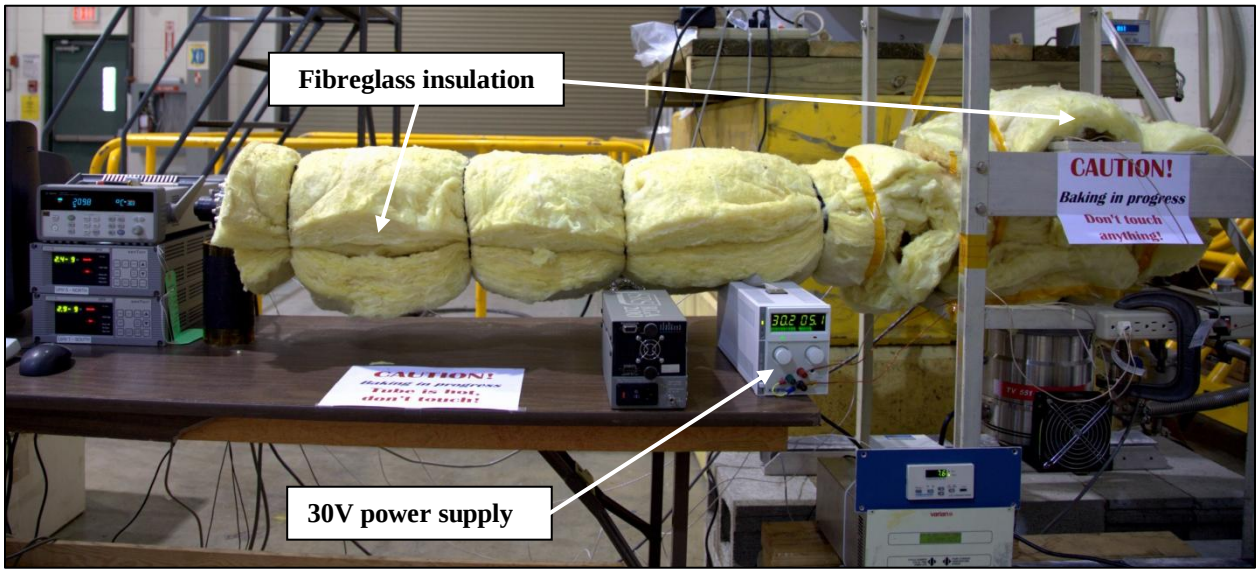


Fig. 5 – The titanium tube and stainless steel cross were wrapped in 2 – 4" of fibreglass insulation to reach the 200 °C baking temperature goal. Note that in the final setup the insulation will have to be less than ¼" thick to allow the 4.5" diameter tube to fit inside the 5.02" diameter superconducting magnet bore.

Temperatures

We used four 4-wire resistance temperature detectors (RTDs) to monitor the baking temperatures (Omega SA1-RTD-4W-120). Three RTDs were attached to the titanium tube (at the North end, middle, and South end) and one RTD was attached to the middle of the stainless steel cross (see Fig. 6). We periodically adjusted the distribution of insulation to try to keep the temperatures uniform.

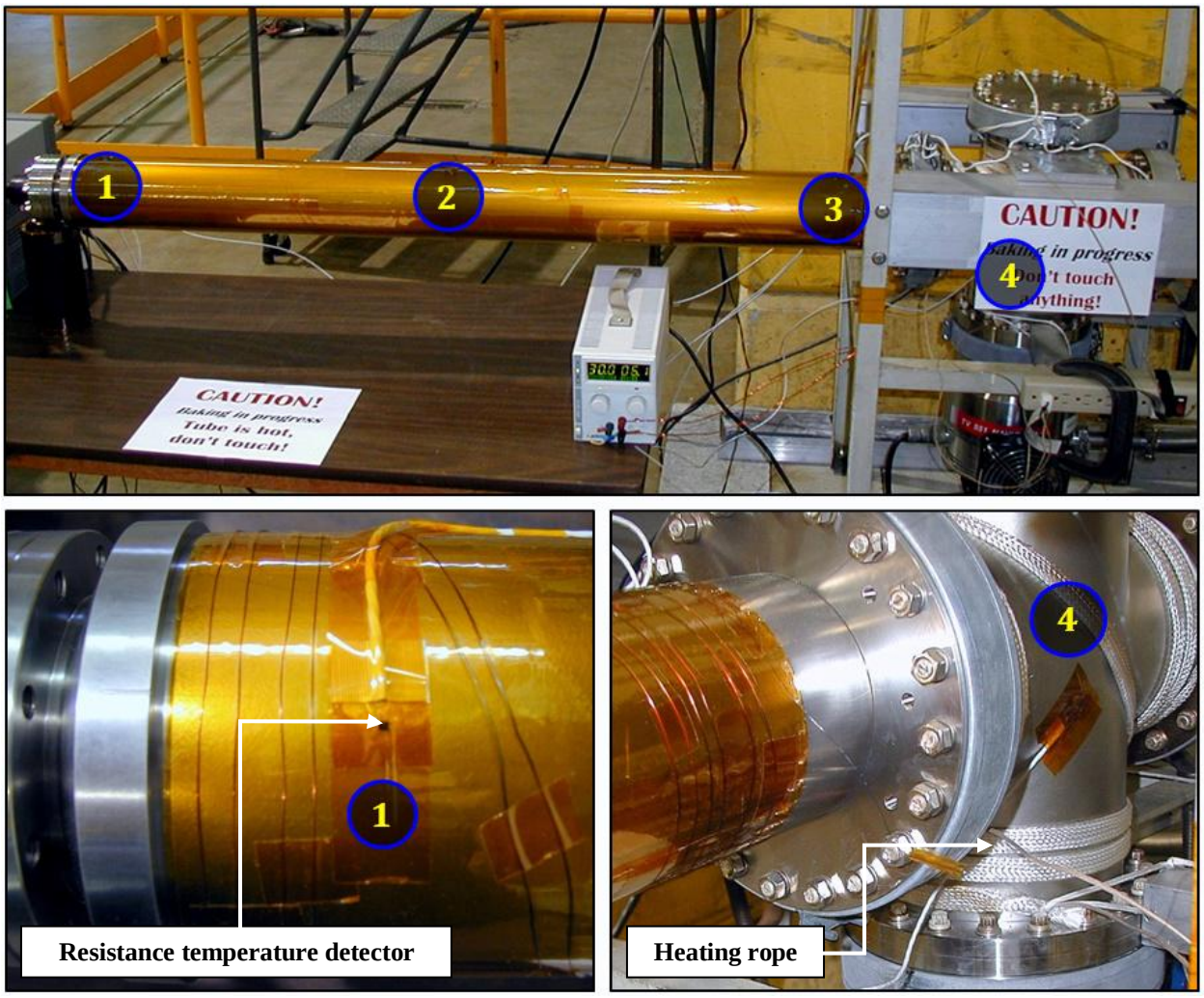


Fig. 6 – The locations of the four 4-wire resistance temperature detectors (RTDs) used to monitor the baking temperatures. This figure shows the original baking system (using 0.010" diameter wires instead of 0.025"), but the same RTDs were used in the new system.

When the stainless steel nipple was installed to troubleshoot a recurring leak, we added 2 more RTDs to the system. One was placed on the South flange of the titanium tube and the other was placed on the North flange of the stainless steel nipple (see Fig. 3 on page 8).

Computer Interface

A computer interface was set up to record the temperatures and pressures once every minute. We connected all six RTDs and both UHV pressure gauges to an Agilent 34970A Data Acquisition module via an Agilent 34901A 20-channel Armature Multiplexer. We used the BenchLink Data Logger 3.0 software to display graphs of the most

recent data. This program could only display the most recent 2500 data points, but it saved all of the data to text files. We used Microsoft Excel to create more graphs to analyze the long-term behaviour of the temperatures and pressures. When the RGA was installed, we took scans using the SRS RGA software (Version 3.105.004). Both the RGA and the Agilent 34970A had RS-232 interfaces, but our computer only had one RS-232 port. However, we were able to use both units simultaneously by using an Edgeport 416 USB Multiport Converter, which connected to the computer via a USB cable.

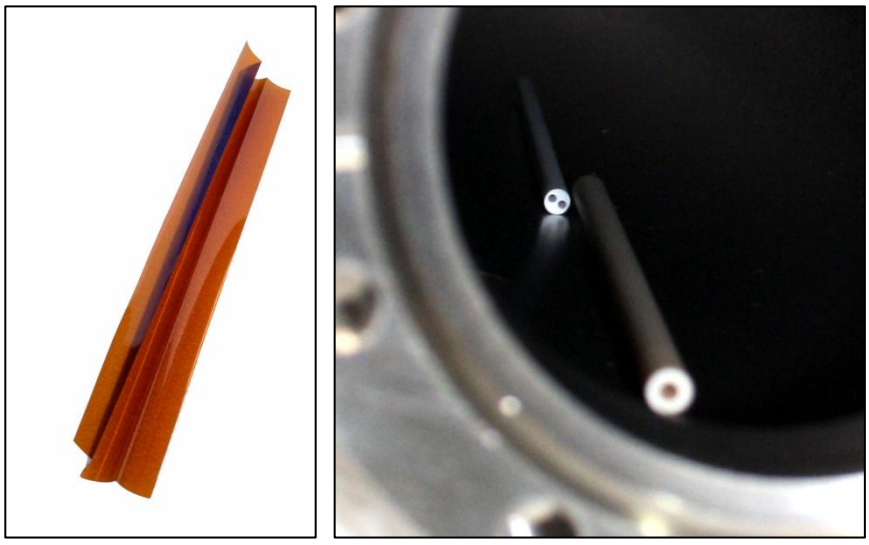
Procedure

Vacuum Tests

To test a given material, we put it through a cycle of baking and cooling. Each cycle started by venting the system using air, removing the previous material, and inserting the new material. Next, the system would be pumped down and baked at 180 – 200 °C for approximately 2 days. Finally, the heaters would be turned off, the system would be allowed to cool for approximately half of a day, and the base pressure would be recorded.

We started by pumping down the empty titanium tube while we were designing the baking system. When the system was ready, we started slowly ramping up the current and adding fibreglass insulation to attempt to make the temperatures uniform throughout the system. After several days of baking, we cooled the system and recorded the base pressure. After testing the empty tube, we went on to do more than ten cycles with different materials inside the vacuum.

The first material we tested was a 20" long by 5" wide sheet of 0.003" thick kapton that had been UHV-cleaned. The sheet had a surface area of 200 in^2, which was twice the estimated surface area that would be needed to insulate all of the leads of the penning trap electrodes. We folded the kapton as shown in Fig. 7 (a) to minimize the surface area that was in contact with the tube wall and therefore minimize the amount of air trapped between the kapton and the wall.



(a) **(b)**

Fig. 7 – Two materials being considered for insulating the penning trap electrode leads were tested inside the titanium vacuum tube. (a) A 20" long by 5" wide sheet of 0.003" thick kapton, folded to minimize contact with the tube walls. (b) Two 6" long ceramic insulators.

For the next baking cycle, we put two 6" long ceramic insulators inside the vacuum as shown in Fig. 7 (b). One insulator had an outside diameter of 0.25" and a single 0.10" diameter hole through the middle. The other insulator had an outside diameter of 0.19" and two 0.06" holes through the middle. The total length was only 12", which was approximately 1% of the total length needed (45 electrode leads, approximately 25" length each). Ideally we would have used many more ceramic insulators, but we did not have any available.

Finally, we covered half of one side of the 20" by 5" kapton sheet with 0.003" thick kapton tape. The tape was not UHV-cleaned; we simply removed the outer winding from the roll of tape and carefully handled the underlying pieces using nitrile gloves. The purposes of this test were to try to understand how necessary the full UHV cleaning procedure was and to see if it was feasible to use ordinary (not UHV-cleaned) kapton tape for repairs.

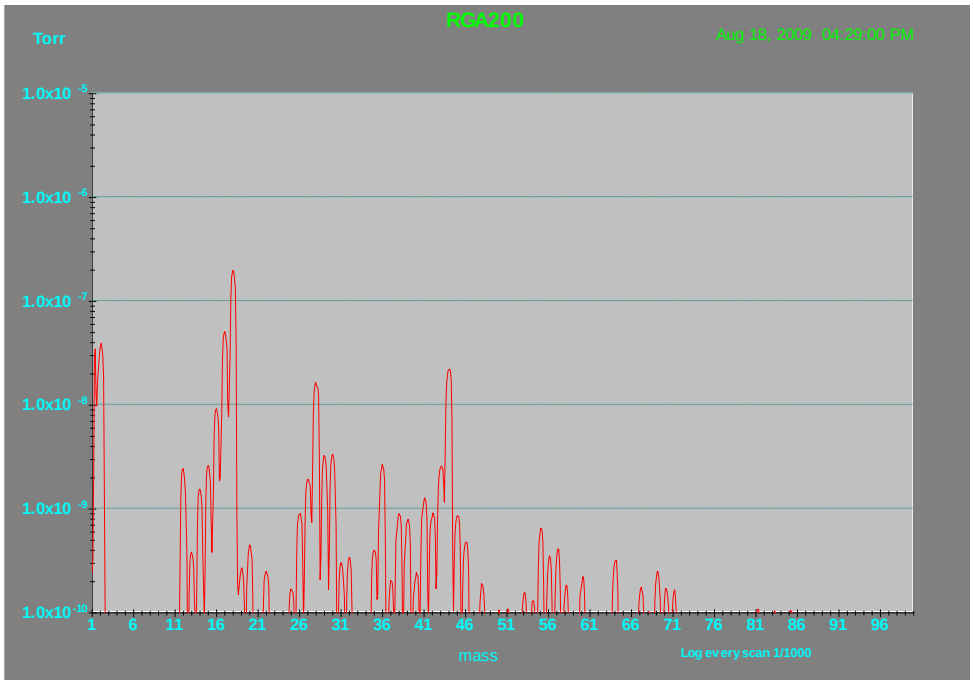
For comparison, between the baking cycles with materials in the vacuum we did cycles with the empty tube. We also repeated the tests of the kapton sheet and the ceramic insulators once the heating wires were changed from 0.010" to 0.025" diameter for the new baking system.

Troubleshooting

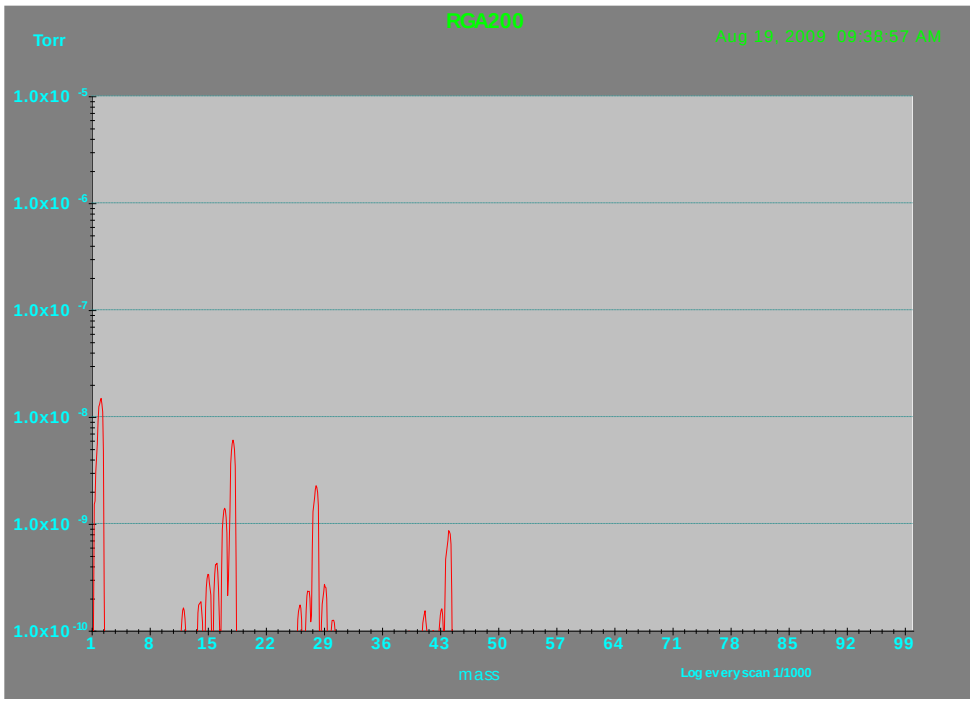
Our first major problem was with the heating system. As described above, the original 0.010" diameter wire eventually broke when its temperature went above 230 °C. We replaced this system with a similar one using sturdier 0.025" diameter wire.

After several months of testing, the base pressure of the tube was not returning to its original level after each baking cycle. We were not sure why, but we suspected that some contaminants had entered the vacuum during one of the many times the tube was opened to insert a new material. Unfortunately, our test setup was not located in a dust free environment – it was in a large experimental hall, near a loading bay door that was sometimes open to the outside air and wind. Even though the vacuum was only open for short times (approximately 10 minutes each changeover), it is quite likely that some contaminants eventually entered the vacuum.

To attempt to improve the base pressure, we installed a 70 l/s turbo pump between the 500 l/s turbo pump and the roughing pump (see Fig. 2 on page 8). This brought the pressure down by a factor of approximately two. We also installed an RGA on the top of the cross to monitor the residual gases present in the system. The RGA was only used briefly, but two scans are included here for comparison with future scans. The first scan (Fig. 8 (a)) was taken shortly after the pumps were turned on to pump down the system after it had been vented. The second scan (Fig. 8 (b)) was taken after 17 hours of pumping. The position of the four highest peaks remained the same, but the magnitude dropped significantly because of the decreased pressure of the vacuum system.



(a)



(b)

Fig. 8 – Residual gas analyzer scans of the vacuum test system. (a) 16:29, August 18, 2009. This scan was taken shortly after the pumps were turned on to pump down the system after it had been vented. (b) 09:39, August 19, 2009. This scan was taken after 17 hours of pumping. Note that the position of the four highest peaks remained the same, but the magnitude dropped significantly.

We had several problems with leaks in the connection between the titanium tube and the stainless steel cross. Near the start of the summer, a leak was fixed by simply tightening the bolts holding the flanges together. Several weeks later, a leak was fixed by changing the copper sealing gasket between the two flanges. These leaks could have been caused by the differences in the thermal expansion coefficients of the copper gaskets and the knife-edges of the titanium and stainless steel flanges. We observed that a tight seal at room temperature could remain tight at 200 °C, but start to leak as the system cooled to room temperature.

Near the end of August, for several cycles in a row we found a leak in the East side of the titanium tube / cross connection. We tried tightening the bolts holding the flanges together and also replacing the copper gasket, but neither strategy fixed the leak. This made us suspect that the problem was in the knife-edge of one the flanges themselves. We attached a nipple (see Fig. 3 on page 8) to separate the two problem flanges and help us determine which one was leaking. After a cycle of baking and cooling, pressures dropped off-scale and the leak was no longer present. We repeated the cycle and again the pressures dropped off-scale. This led us to conclude that the individual flanges were not damaged; it was just something about the particular way they were put together that caused the leaks.

Results

After an initial pumpdown for approximately 25 days, we achieved a base pressure of 1.2×10^{-10} Torr on the North gauge and 9.2×10^{-11} Torr on the South gauge. After baking for approximately 4 days at an average temperature of approximately 185 °C and then cooling for 5 hours, both pressures dropped below 1.5×10^{-11} Torr (the lower limit of the Sentorr gauge controllers). These pressures were also below the 5×10^{-11} Torr lower limit of the most accurate region of measurement for the UHV-24p gauges, and approaching the 5×10^{-12} Torr x-ray limit.

We observed that in all baking tests the pressures went up by several orders of magnitude while temperatures increased. Once the temperatures stabilized, the pressures would slowly start to fall off as the gases released from the vacuum chamber walls were pumped away. After several days of baking at 180 – 200°C, the pressures were usually in the low 10^{-8} to medium 10^{-9} Torr range. Once the heaters were turned off, the temperatures and pressures would quickly drop. For all materials tested, the pressures dropped off-scale (below 1.5×10^{-11} Torr) after the system was cooled for approximately half of a day.

Analysis

I went through all the data and compared the pressures and temperatures after baking and after cooling down for several of the baking cycles. I only focussed on the cycles using the new baking system (with the 0.025” heating wires) because this system heated the tube most uniformly. I graphed the two UHV gauge pressures and the average temperature from the three RTDs along the tube for two cycles – one with the kapton sheet in the vacuum, and the other with the two ceramic insulators in the vacuum. Next, I compared the cool-down curves and noted the amount of time it took for the pressures to drop off-scale once the heaters were turned off. This analysis was done to look more closely at the results; however, it would be a mistake to conclude too much from it because the test conditions were too different (in terms of geometry, heat capacity, surface area, and porosity of the materials) to make a valid comparison.

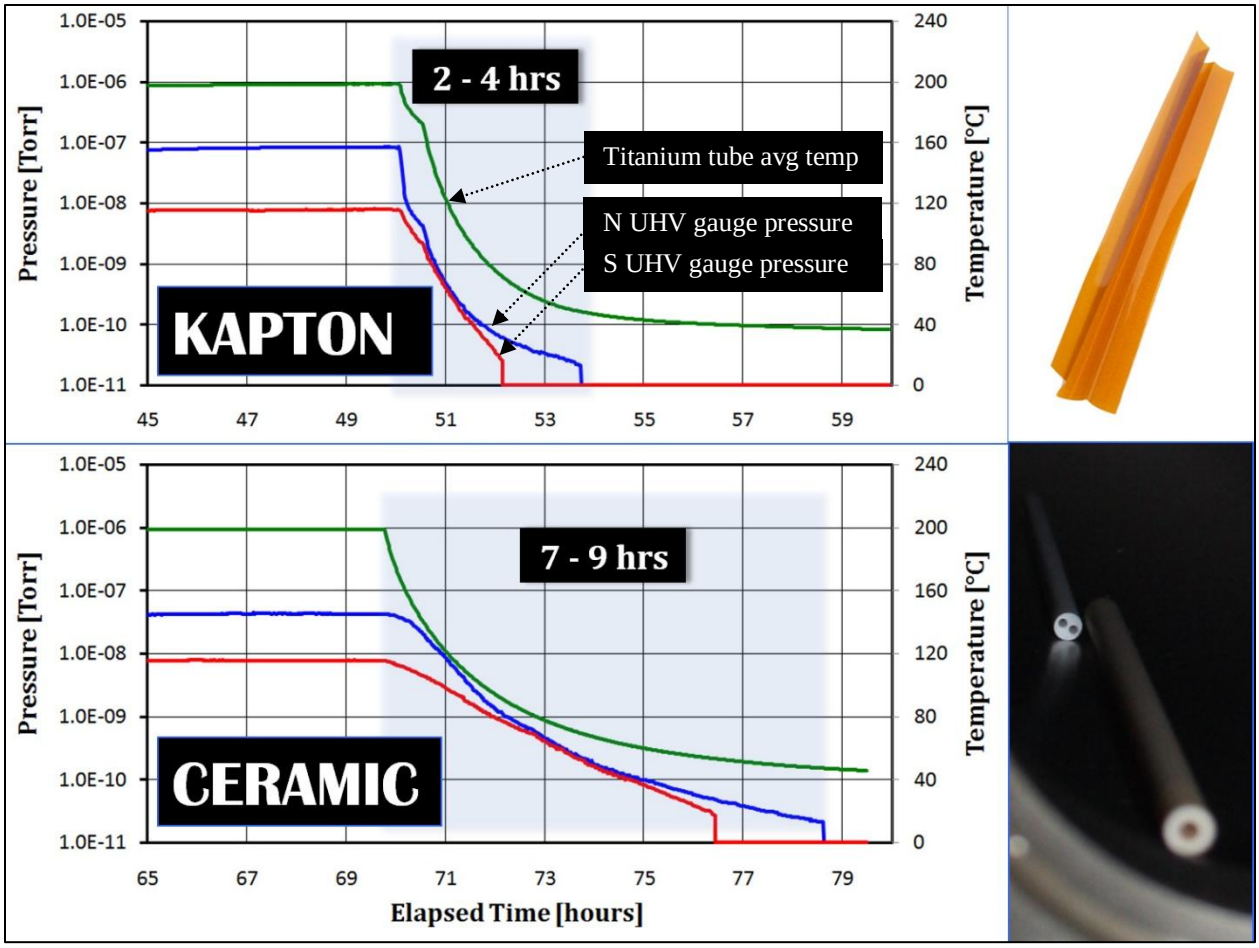


Fig. 9 – Comparison of the cool-down of the titanium tube when it contained a 20" by 5" sheet of 0.003" thick kapton (top) or two 6" long ceramic insulators (bottom). It seems like the kapton had less of an effect on the vacuum, but due to many differences in the samples (geometry, heat capacity, surface area, porosity) further tests would be needed to make this conclusion. The main feature of the graphs is that for both materials, the pressure in the titanium tube drops off-scale (below 1.5×10^{-11} Torr) in less than half a day of cooling after baking.

Conclusions

Vacuum Tests

All of the objectives of this project were achieved this summer. First, we put together a pumping station for the titanium vacuum tube and designed a baking system to heat it. After baking for approximately 4 days at an average temperature of approximately 185 °C and then cooling for 5 hours, the pressure in the tube dropped below 1.5×10^{-11} Torr (the lower limit of the Sentorr gauge controllers). This pressure is among the lowest pressures ever seen on any gauge at TRIUMF. This means that we should have pressures low enough to allow HCI to pass through the system without undergoing too much charge exchange. Finally, we tested several critical materials being considered for insulating the leads of the CPET electrodes. Separate tests were done with a sheet of 0.003" thick kapton plastic and then two 6" long ceramic insulators inside the titanium vacuum tube. In both tests, the pressure dropped below 1.5×10^{-11} Torr after baking for approximately 2 days at a temperature of 180 – 200 °C and then cooling for

approximately half of a day. Further tests with more similar sample conditions would be needed to determine which of the two materials has the least effect on the vacuum. The main conclusion we made was that both materials are acceptable for UHV use.

My Involvement

I played a major role in this project from start to finish. Some of the main things I did were setting up the pumping station, designing and installing the heating system, repairing the system when it broke, setting up the computer interface, controlling and monitoring the baking system, changing the materials inside the vacuum, and analyzing the data. I also gave an oral presentation about this project at the TRIUMF Summer Student Symposium and wrote this report (which is intended to give a summary of the tests this summer and also give enough detailed information to help future TITAN collaborators working with the CPET).

Future Outlook

In September 2009, the test setup will be moved to a dust-free environment and further vacuum tests will be performed. The penning trap design is still being finalized but the tests done this summer will be helpful in choosing the insulation material. The plan is that by early 2010 the trap will be constructed and shipped to TRIUMF. By that time a more compact baking system will have been designed, installed, and tested. The precise location of the axis of the magnetic field of the 7 Tesla superconducting magnet will also have been measured by then. The TITAN platform will be extended, and the whole setup will be moved into the TITAN beamline between the switchyard and the MPET. Once on the platform, the titanium tube (containing the penning trap) will be placed inside the superconducting magnet, and the axis of the tube will be aligned with the axis of the magnetic field. Once the system is pumped down, baked, and cooled, mass measurement experiments can continue. The CPET will store highly charged ions for up to a second and allow them to be cooled by a cold medium (electrons or protons). The cooled HCI will then be extracted and sent to the MPET for ultra-precise mass measurement. The presence of the CPET will increase the resolution of these mass measurements by a factor of at least 10, from approximately 10^{-8} to 10^{-9}.

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Appendix A – TRIUMF UHV Cleaning and Assembly Procedures

Written in August 2007 by Mel Good, AScT.

Introduction:

Due to the detrimental effects of oils and contaminants on an ultra-high vacuum (UHV) system, the following cleaning and assembly procedures have been developed to help minimize the contamination of components used in a UHV system. This is a living document; its purpose is to document the procedures as they are developed and fine-tuned and to convey the procedures to individuals who may not be familiar with UHV practice.

Cleaning:

1.) Inspect the components first to ensure that all required venting holes and slots are in place. If components are excessively greasy or dirty, use a solvent bath to remove the grease. Pay special attention to any holes and tapped threads. Air guns can also be used to ensure that machining chips are removed from any holes or tapped threads.
2.) Wash all components with soapy water (20% simple green/water mix). Again pay special attention to any holes and tapped threads. Rinse with hot city water. The purpose of this step is to ensure that all the grease, light oils and machining chips are completely removed from the part.
3.) Put the component in a clean container and submerge with soapy water mix (same mix ratio as in step #2 above). Immerse container into an ultrasonic cleaner and agitate for 30 min. Ensure that the transfer medium in the ultrasonic cleaner does not contaminate the cleaning solution used.
4.) Transfer the component to another clean container and rinse with hot city water.
5.) Leaving the component in the same container, rinse with distilled or de-ionized water.
6.) After rinsing, fill container to a level sufficient to submerge the part. Immerse the container into an ultrasonic cleaner and agitate for 30 min.
7.) Do a final rinse of the component in the container with distilled or de-ionized water.
8.) Transfer the component to a clean container and allow it to air dry in a dust free environment. The part can be left in the container for clean storage.
9.) Use clean gloves onward from step #2 and post process.

For best results the following things should be kept in mind:

1.) Do NOT mix different materials in the same wash, corrosion reactions can occur in the alkaline soapy solution causing oxide coatings to for on some metals and corrosive reactions on others.
2.) Use different soapy mixes for different materials. Do not use the same soapy water mix for aluminum and then for copper. The same oxide and corrosive reactions can occur due to the ions being dissolved in the mix.
3.) the part looks dirty, then it probably is and further cleaning is necessary.
4.) If oxide coatings become problematic, especially with aluminum and copper, then shorten the duration of steps #3 & #6 and try to shorten the time required to air-dry the part.
5.) Clean gloves must be used during the complete cleaning process and especially steps #3 – 9. When placing gloves on one's hands, care must be exercised so that the working surfaces of the gloves are not contaminated with hand oils. Gloves cannot be considered clean once they have been used on tools or doorknobs.
6.) Immediately replace a glove once it has been perforated.

Assembly:

It is a requirement that two people work together when assembling or disassembling UHV components. All components used in a UHV system MUST first be cleaned to the UHV Standards described in the procedure listed above.

1.) Person #1 is to wear clean gloves. Care must be taken when placing gloves on one's hands. It is vital to keep the working surfaces of the gloves free from contaminants such as dirt, grease, or skin oils. Person #1's role is to handle and assemble the various UHV cleaned components used in the UHV system.
2.) Person #2 is not required to wear gloves as their role is as a "dirty" helper for person #1. Person #2's major responsibility is to ensure that person #1 remains clean. If a component requires tightening, then person #2 gets the tool required, cleans the working end of the tool with acetone and a clean tissue and then tightens the component while person #1 holds the clean assembly. Under no circumstance does person #1 handle tools and person #2 handle clean components.
3.) For components are contained in clean bags or storage containers, the outside surfaces of the bags or storage containers MUST be considered contaminated. In this instance, person #2 opens the storage container or bag and places the bag or container in such a way that person #1 can remove the item from the container or bag without touching anything but the component.

For best results the following things should be kept in mind:

1.) When placing gloves on one's hands, care must be exercised so that the working surfaces of the gloves are not contaminated with hand oils. Only handle the gloves by the cuffs when placing a glove on one's hand. If your hand does not completely fit into a glove, DO NOT use an ungloved hand to complete the fit. Put a glove on the other hand and then try to work the glove or gloves onto your hands.
2.) Gloves cannot be considered clean once they have been used to handle tools, bags, containers, or doorknobs. Put another clean pair of gloves onto your hands.
3.) Immediately replace a glove once it has been contaminated or perforated.